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Study of DISTRIBUTORS for APPLYING DRY MATERIALS by AIRPLANE

JAMES E. HENRY

OHIO AGRICULTURAL EXPERIMENT STATION
Wooster, Ohio

CONTENTS

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ACKNOWLEDGMENTS

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COVER PHOTOGRAPH: Flight testing a distributor using the deposit measuring trays, wind indicator, and altitude sight.

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STUDIES of DISTRIBUTORS for APPLYING DRY MATERIALS by AIRPLANE

INTRODUCTION

JAMES E. HENRY*

After World War II, the airplane came into rather extensive use for the application of agricultural materials to farm land. At this time, war surplus planes were easily available and there were many pilots interested in continuing their flying. Recent statistics on aerial farm operations in the United States indicate that about 52 million acres are treated each year. The largest acreage covered has been for insect control, with weed control, fertilization, defoliation, seeding and other uses in decreasing amounts. More than 800,000 hours of aircraft flying time were required to do this work (1)**.

A project was initiated in agricultural aviation by the Agricultural Experiment Station in 1950. The first work was mostly concerned with methods of measuring the deposition of aerially applied materials (2). In these and other studies, it was observed that changes were needed in aerial application equipment to improve the distribution pattern and control the rate of application.

Most of the early equipment consisted of a hopper with a sliding gate over an outlet in the bottom for controlling the flow. A distributor built by trial and error means was attached below this opening for spreading the material. The resulting swath was usually far from ideal.

The work reported here was directed towards obtaining information to provide a basis for the design of a distributor for applying dry material such as seed, fertilizers, dusts, and granular materials.

Both wind tunnel and flight studies were conducted on the ram-air or Venturi-type distributor. The work began with the wind tunnel study using a test distributor which was adjustable in air inlet opening, outlet, and throat size. Determinations were made of the effects of these variables on the distributor capacities. A flight study

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*Instructor, Agricultural Engineering Department, Ohio Agricultural Experiment Station.

**Numbers in parenthesis refer to appended references.

followed, using a test distributor to determine additional distributor design factors which contribute to a wider swath. Tests were then conducted with a complete distributor to determine and correlate factors which produce a desirable distribution pattern and swath width.

The function of the ram-air distributor is to give the material sufficient energy and proper direction to produce a desirable swath width and distribution pattern. Some of the factors that affect the swath width and distribution pattern include natural air currents (thermals, cross-winds, and turbulence), air currents caused by the aircraft itself (propeller slip stream, wing vortices, and currents from various structural members) aircraft speed and altitude, type of material being applied, application rate, and the distributor size and configuration.

WIND TUNNEL STUDIES

Objectives:

The wind tunnel (Figure 1.) was used to determine some of the design characteristics such as the amount of energy available from the

Fig. 1.—General view of the portable wind tunnel showing the distributor test section in place, manometers, and metering device.

ram-air, the effects of constrictions at the throat (Venturi shapes), and distributor size (in cross-sectional area), and the effects of varying the operating conditions such as the material type, dispensing rate, and air speed.

Procedure:

Some calculations were first made to estimate how large a distributor must be to apply at least 150 pounds of material per acre. A wind tunnel, a test section of an adjustable ram-air distributor, and air flow measuring devices were designed and built. A positive displacement type metering device, previously developed, was used to control the flow of material into the throat of the distributor test section (3).

The distributor section, (Figure 2), was 6 inches wide, 3 feet long and adjustable in depth from 3.5 inches to 9.5 inches. It had removable inserts 1, 1½, 2, 2½, and 3 inches thick, to vary the constriction of the Venturi, and had straight clear plastic sides. It was possible to vary the amount of constriction from none to a ratio of the distributor opening size to the throat size of five to one. The distributor size, in depth, was changed by moving the adjustable bottom up and down.

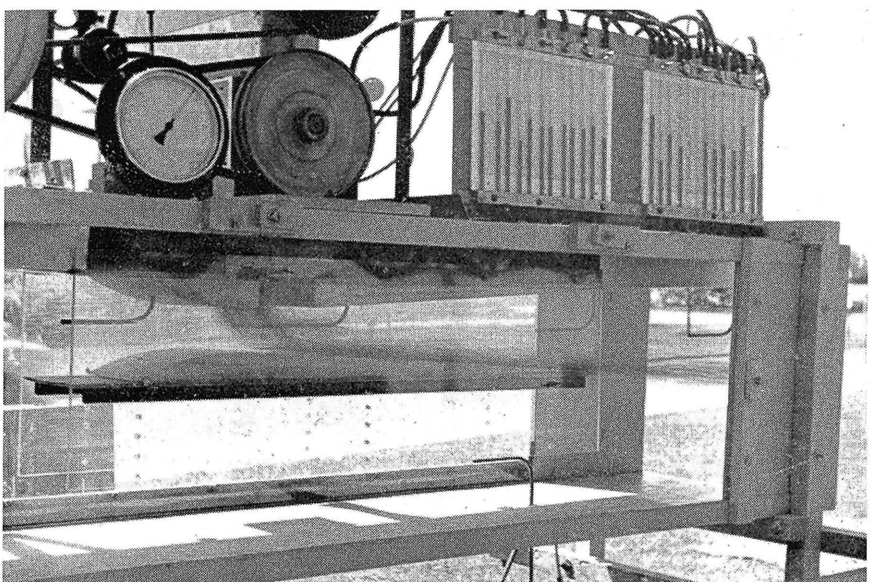

Fig. 2.—Close up of wind tunnel and adjustable test distributor used. In this example approximately 140 pounds of wheat per minute is being used with a wind tunnel airspeed of 80 mph.

Pitot-static tubes and differential manometers were used to measure the air velocity and static pressure. A pitot-static tube was placed in each of the following locations: in front of the distributor, just inside the distributor inlet opening, in the throat of the distributor, near the distributor outlet, behind, and below the distributor (Figure 2). The manometer readings were quickly recorded by placing a sheet of paper behind each group and marking the liquid levels so they could be measured later. Several runs could be made on one sheet by using colored pencils.

Tests were made using the various distributor inserts, opening sizes (depth of distributor), air speeds, and feed rates with wheat as the material distributed. Similar runs were also made with several types of fertilizers and dusts. Difficulty was encountered with finely ground fertilizer and dust plugging the pitot tubes; however, if they were blown out before each run, they functioned well.

Following the above tests, a series of runs were made while taking highspeed movies (1800 frames per second) for use in actually measuring the particle velocities in the distributor test section and to provide a means of further studying the distributor action. The wind tunnel data, used for several of the graphs are from this series of tests.

In the wind tunnel used for this study, it was not possible to put deflecting vanes on the distributor outlet and measure the resulting swath width. Therefore, in order to estimate what swath width would result from the lateral velocity given to the particles by a distributor, more information was needed. The drag, vertical displacement, and particle travel was calculated using 1/8 inch diameter vetch seeds in an attempt to determine the swath width that would be produced by a certain velocity (4).

Since wheat was used in the wind tunnel tests, it was decided to determine experimentally how far it would travel by projecting kernels at various speeds from various heights. This also served to check the calculated data. The wheat was accelerated by placing it in a drum rotating at a known speed and was then projected by releasing the particles. The horizontal distance traveled was doubled to arrive at an estimated swath width. These calculations and experiments were conducted in still air. The results would no doubt be somewhat different if the particles were discharged from a moving aircraft because of the forward motion and air currents created by the aircraft.

Results:

It was found, that when the cross-sectional area of the distributor throat was reduced to one-half of the inlet area or less, the velocity of

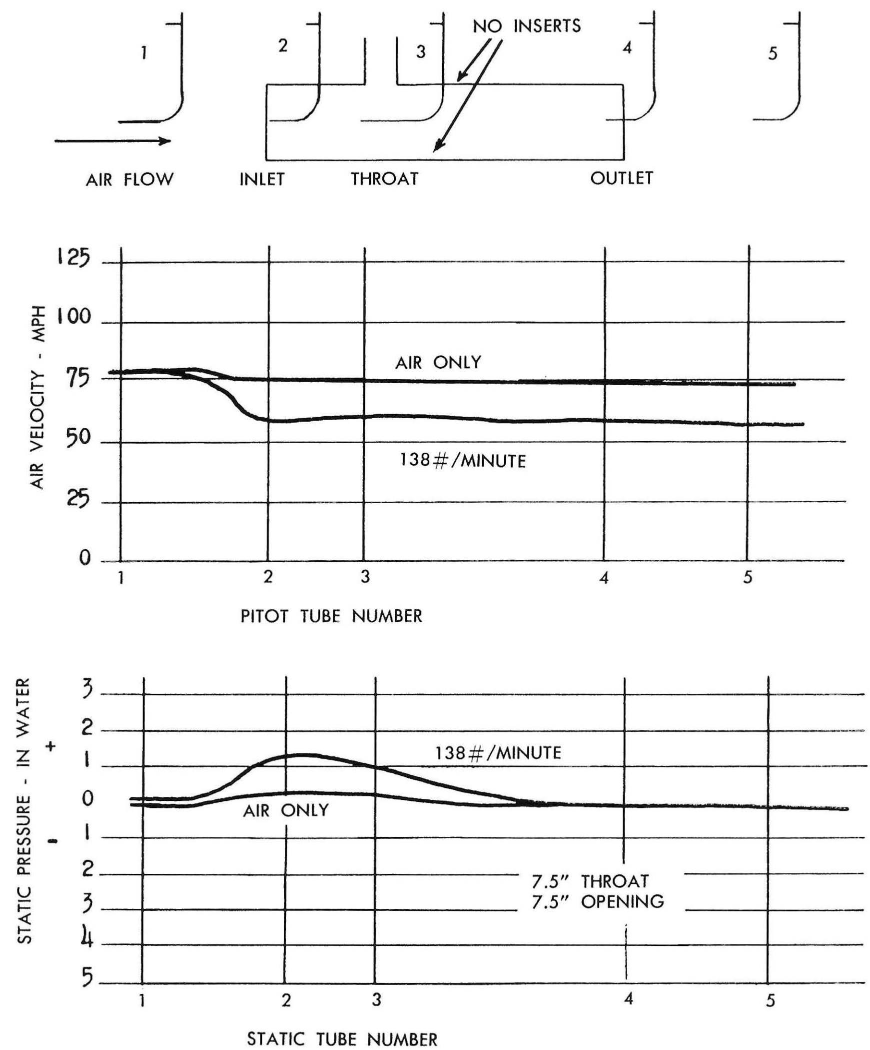

Fig. 3.—No throat constriction.

Figs. 3-5.—Cross sectional view of the wind tunnel test distributor showing the location of the pitot-static tubes and resulting air velocities and static pressures with air only and with a wheat flow rate of 138 pounds per minute.

the wheat leaving the outlet decreased considerably. The wheat outlet velocity also decreased when the overall cross-sectional area of the distributor was decreased, when the material flow rate was increased, or when the air speed was decreased. Figures 3 to 5 illustrate three of the distributor configurations, the pitot-static tube locations, and a cross

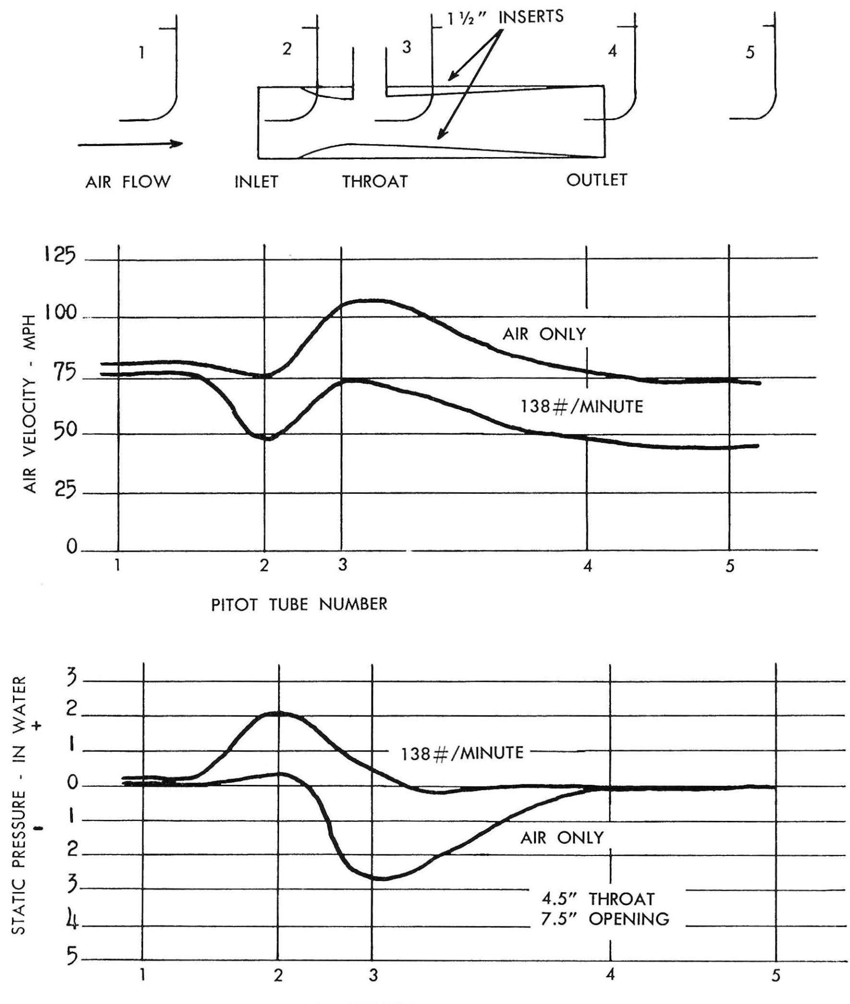

Fig. 4.—Moderate throat constriction.

section of the air flow and static pressures. Notice the decrease in inlet and outlet air velocities as the throat size is reduced.

With no constriction at the throat as compared to a moderate one (down to approximately 2/3 of the inlet area) there was very

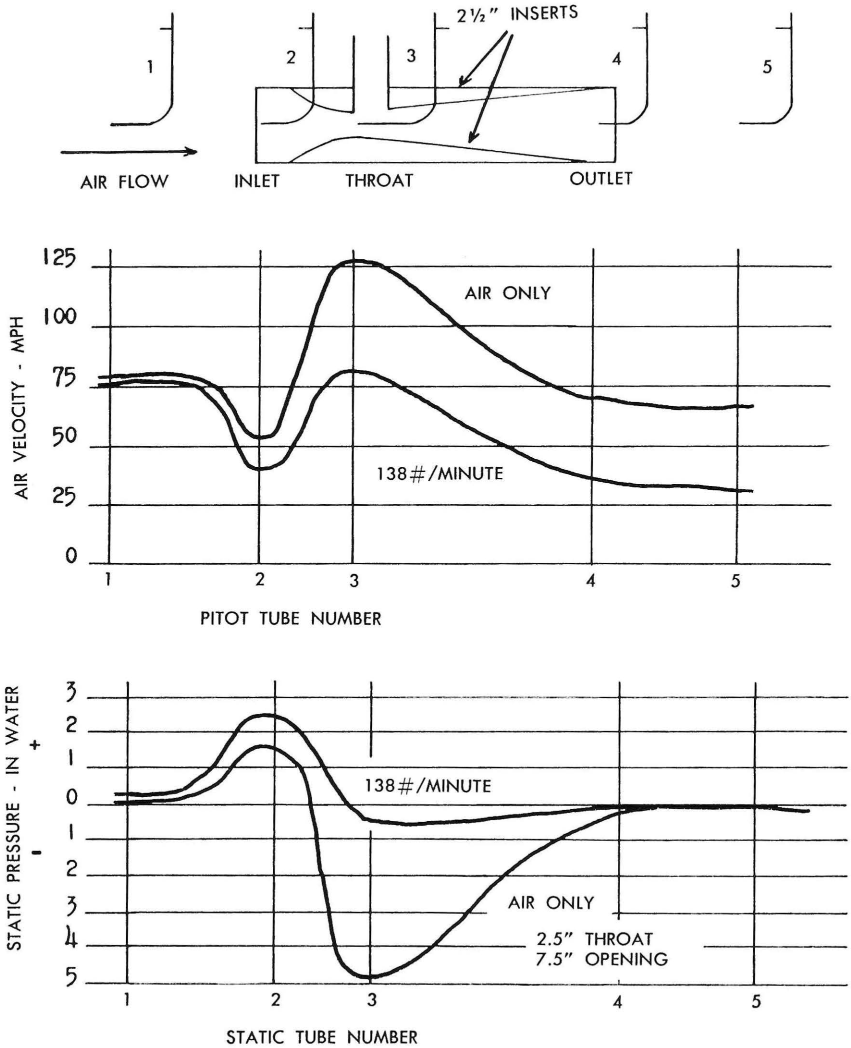

Fig. 5.—Considerable throat constriction.

little difference in the velocity of the wheat at the outlet. A moderate amount of constriction may help the flow of material from the hopper where a positive displacement type metering device is not being used. A Venturi with too much constriction is quickly overloaded when the feed rate is increased which results in a low air velocity near the outlet allowing the material to slow down and possibly settle on the bottom (Figures 5, 6, and 11).

The air velocity and wheat outlet velocity increased as the distributor size, in depth, was increased. This is shown in Figure 7 along with the wheat/air ratio. The wheat/air ratio is defined as being the pounds of wheat per pound of air flowing through the distributor. The small distributor, 5½″ depth, was overloaded easily, resulting in low velocities similar to those obtained with the small throat sizes.

The velocities decreased as the wheat flow rate was increased as shown in Figure 8. This also gives an indication of the load on the distributor and explains why narrower swaths are obtained with higher application rates.

The velocities increased as the tunnel airspeed was increased (Figure 9). In order to keep the same application rate in flight, however, the wheat flow rate would have to be increased, which would tend to nullify the increase.

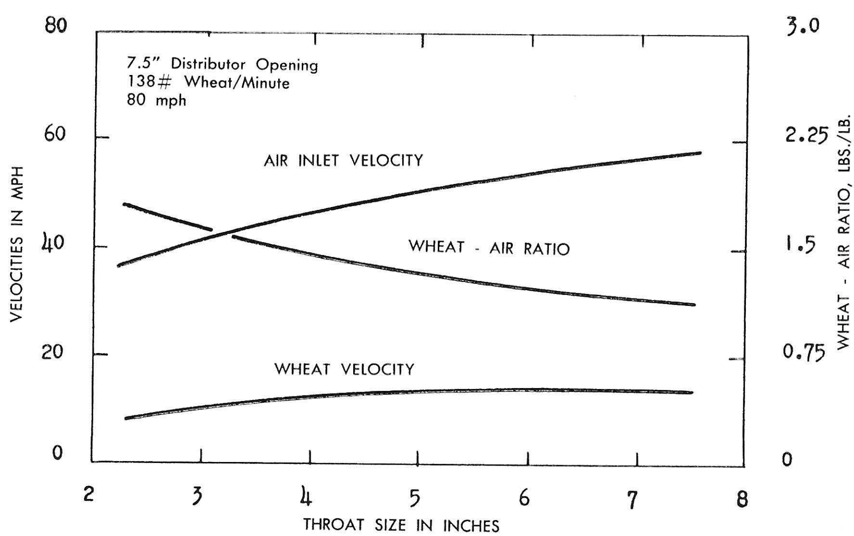

Fig. 6.—Air inlet velocity, wheat outlet velocity, and wheat/air ratio as influenced by the throat size (amount of constriction in the Venturi).

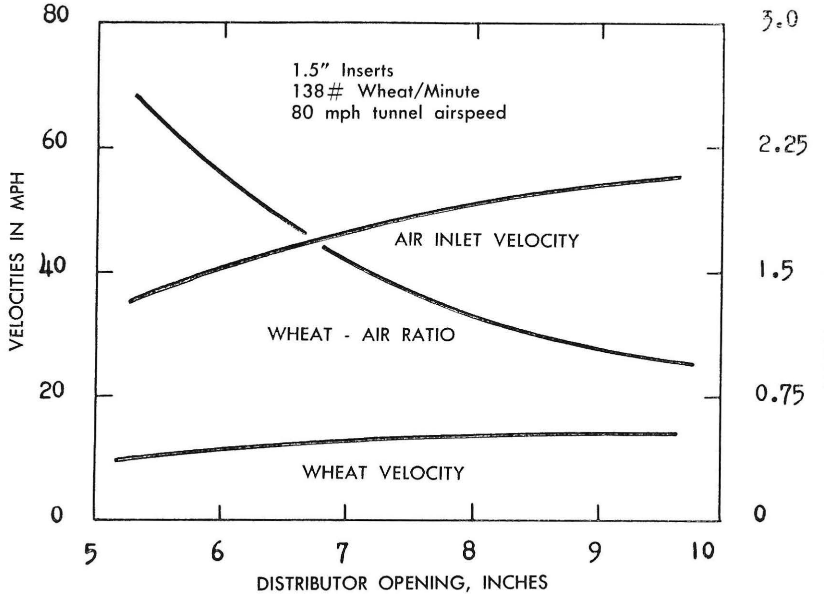

Fig. 7.—Air inlet velocity, wheat outlet velocity, and wheat-air ratio as influenced by the distributor opening size (in depth).

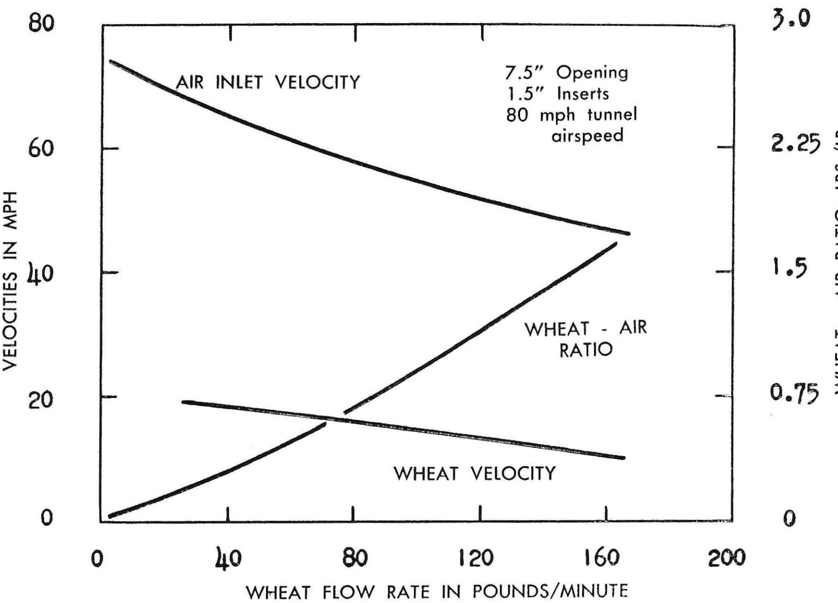

Fig. 8.—Air inlet velocity, wheat outlet velocity, and the wheat-air ratio as influenced by the wheat flow rate.

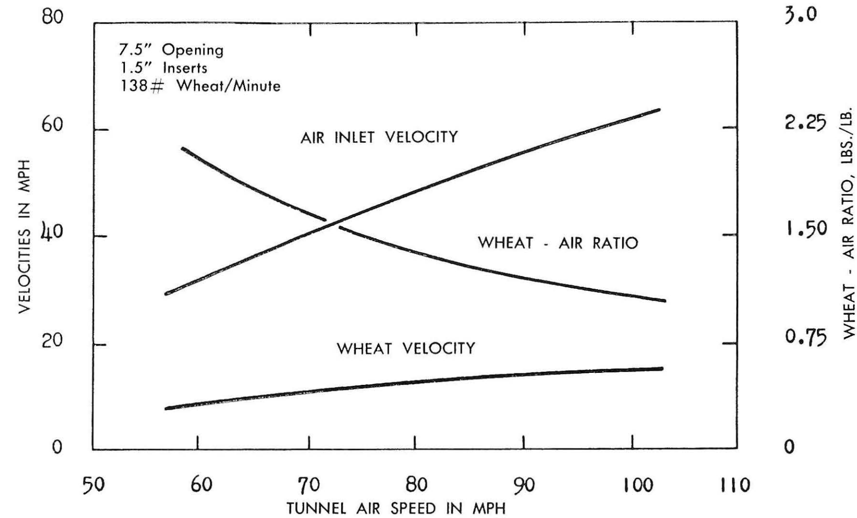

Fig. 9.—Air inlet velocity, wheat outlet velocity, and wheat-air ratio as influenced by the wind tunnel air speed.

Figure 10 shows a vertical cross section of the wheat velocity at the outlet with three opening sizes. With the smaller 5.5″ opening, the distributor was overloaded and the major portion of the wheat flowed

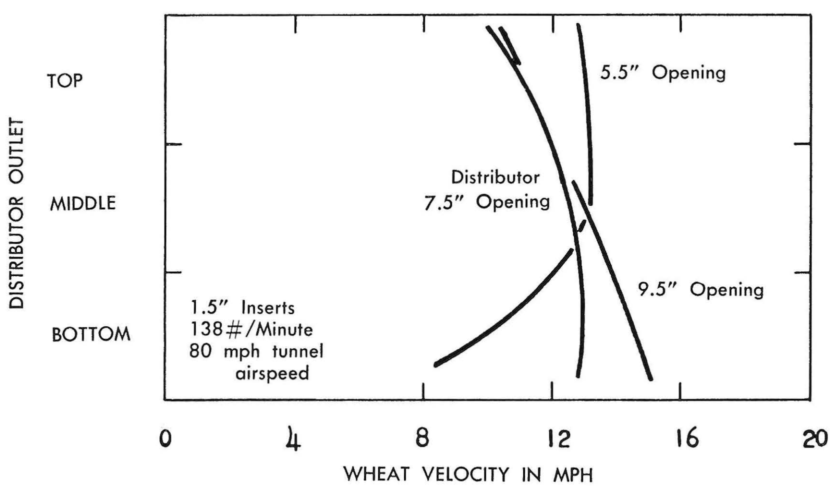

Fig. 10.—Variation in the wheat grain velocity from top to bottom of the distributor outlet.

along the bottom of the distributor. With the larger 9.5" opening, the wheat was generally carried in the air stream and the air tended to flow under the stream of wheat.

The acceleration of the wheat grain is shown in Figure 11. The wheat dropped into the distributor at the throat and was carried to the outlet 24 inches from the throat. The 1½" and 2½" inserts were used for the curves shown. This gave a 4½" and 2½" throat depth respectively. Note that the particle velocities actually slowed down near the outlet when the 2½" throat was used. This indicates that the constricted throat was overloaded and decreased the air flow through the distributor. Also the relatively abrupt change in cross section may have created additional turbulence which would decrease the efficiency (also see Figure 5).

At slow air speeds and with small openings or throat sizes it was possible to completely choke the distributor. At medium air speeds the wheat or granular fertilizer flowed out in a layer on the bottom of the distributor. At the higher air speeds and with the larger distributor opening and throat sizes, wheat or granular fertilizer was carried in the

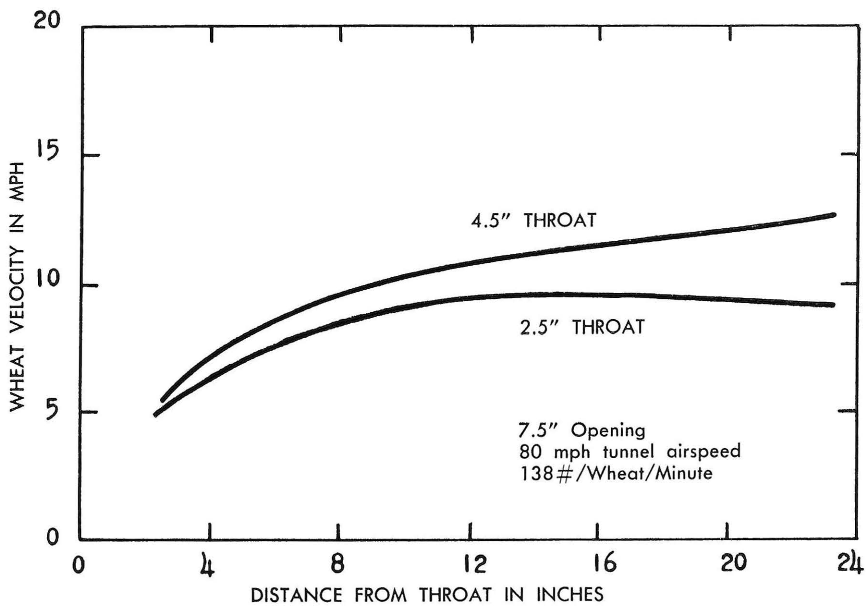

Fig. 11.—Wheat grain velocity vs the distance from the throat. This gives a cross section of how the grains accelerated as they were carried from the distributor throat to the outlet.

air stream. Finely ground materials such as dusts, were generally carried in the air stream.

By use of the high speed movies taken during the wind tunnel tests, it was determined that the wheat velocity at the outlet was in most cases approximately ¼ that of the air inlet velocity (Figures 6 to 9).

Tabulated data from the high speed movie series are included in the appendix.

The information gained from projecting the wheat particles at various velocities showed that wheat with a lateral velocity of 12 m.p.h. would give an estimated 35-foot swath from a 20-foot altitude (Figure 12). Thus, if the distributor projected the wheat at a 60° angle, the actual velocity would have to be approxicately 15 m.p.h. This was about the maximum obtained, at 138 pounds of wheat per minute and 80 m.p.h., during the wind tunnel tests. This would give an application rate of approximately 100 pounds per acre when using a 24-inch wide distributor (at the throat) at 80 m.p.h.

It should again be noted that these experiments to estimate swath width were conducted in still air. In flight the forward velocity would tend to decrease the swath width because of an increased drag on the particles (5), while the air currents would tend to increase the swath

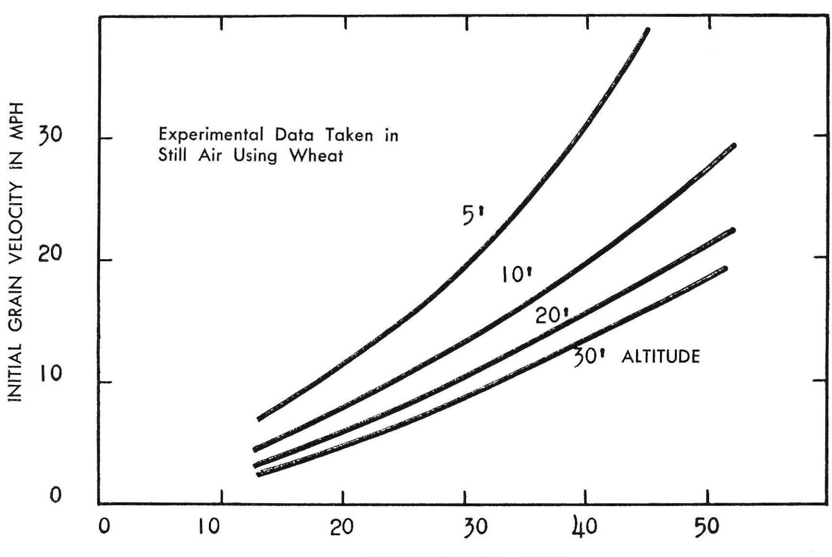

Fig. 12.—Estimated swath widths that would be produced at several flight altitudes as influenced by the lateral velocity of wheat grain.

width. The experimental data agreed quite well with the earlier calculations (4).

This data indicates that in order to obtain a wide swath at a high application rate of materials such as wheat or granular fertilizer, it is necessary to use a large distributor (in cross-sectional area at least) with a moderate or no constriction at the throat. Increasing the flight altitude would also contribute to widening the swath when applying these materials.

FLIGHT STUDIES

Objectives:

Following the wind tunnel studies, flight studies were conducted to evaluate additional factors that would contribute to a wide swath and produce a desirable distribution pattern. The flight studies also served to check the wind tunnel results and correlate them with actual flight conditions.

Procedure:

An airplane was equipped with a test distributor (Figure 13 and 14) with a detachable straight section immediately behind the chute, three sets of detachable deflecting vanes or ducts, and two sets of extensions for attachment on the outboard end of the deflecting vanes. Also, two outlet angles were used with one set of the deflecting vanes.

Thus it was possible to study the variables of distributor length, radius and location of deflecting vanes, width at the outlet, and the outlet angle. The effects of varying the application rate and altitude were also observed. A granular fertilizer and 30-60 mesh granular clay were the materials applied during these tests.

In order to determine the effects of the variables referred to above, deposits were measured to obtain the application rate, swath distribution, and swath width. The air speed and static pressures were measured at two locations in the distributor and the air speed was also measured in front of the distributor and on a wing strut. The aircraft altitude (wheel height) as well as wind speed and direction were measured. The material dispensing rate was controlled with a vaned rotor metering device (Figure 15) driven from the aircraft engine through a variable speed hydraulic drive. This metering device was of the same general type as the one used in the wind tunnel. A pressure compensating flow control valve made it very easy to control the dispensing rate quite accurately (7) by controlling the oil flow to a hydraulic motor which operates the metering device.

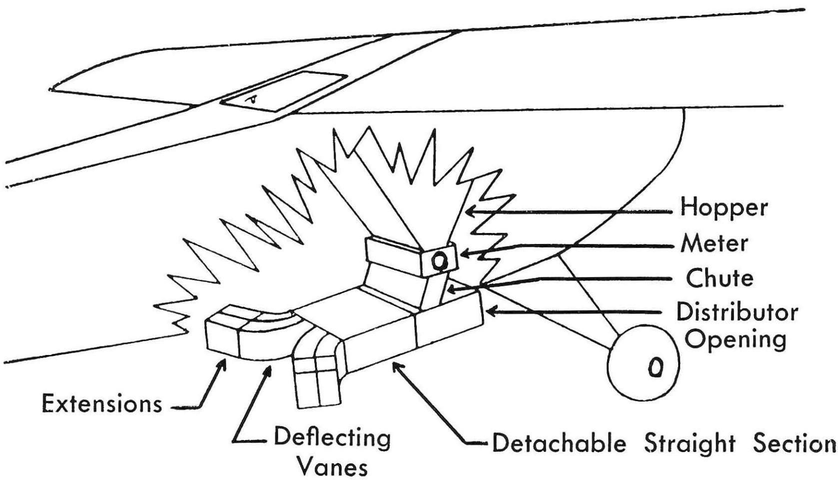

Fig. 13.—Schematic sketch showing location of the equipment in the airplane and an example of the test distributor.

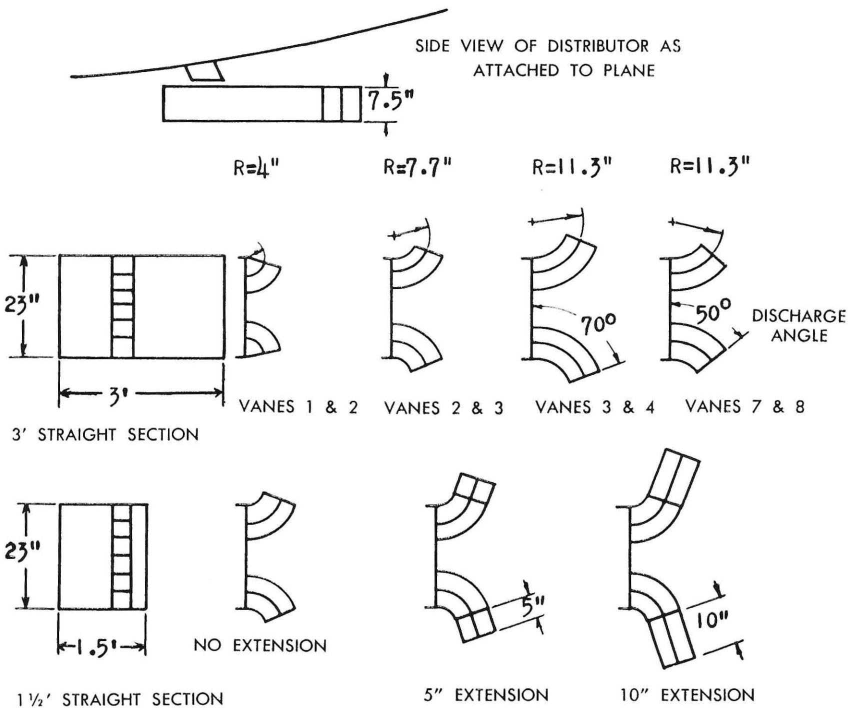

Fig. 14.—The various flight test distributor attachments or variables. All combinations of vanes, extensions, and straight sections were used.

The deposits were measured by collecting the material in three-foot square canvas-bottom trays, placed six feet center to center across the flight path. The material collected in each tray was measured in a tapered, clear plastic tube which had been calibrated for each material. The aircraft altitude was determined by the use of a triangulation sight mechanism. The wind direction and speed were obtained with a combination wind vane and swinging vane anemometer (6).

The equipment was installed on an 85-horsepower Piper J-3 airplane. In general, the test flights were made with the aircraft headed into the wind at an altitude of 25 feet above the measuring trays with an air speed of 70 to 75 miles per hour.

Following the above tests, a "complete" distributor (Figure 16) was designed and built in order to co-ordinate the information gained from the "test" distributor studies and to obtain more information on factors affecting the distribution pattern. The complete distributor was 8 inches deep by 22 inches wide at the inlet, 31 inches long, and approximately 6 feet wide by 4 inches deep at the outlet. The deflecting vanes were adjustable. An air foil was attached to the leading

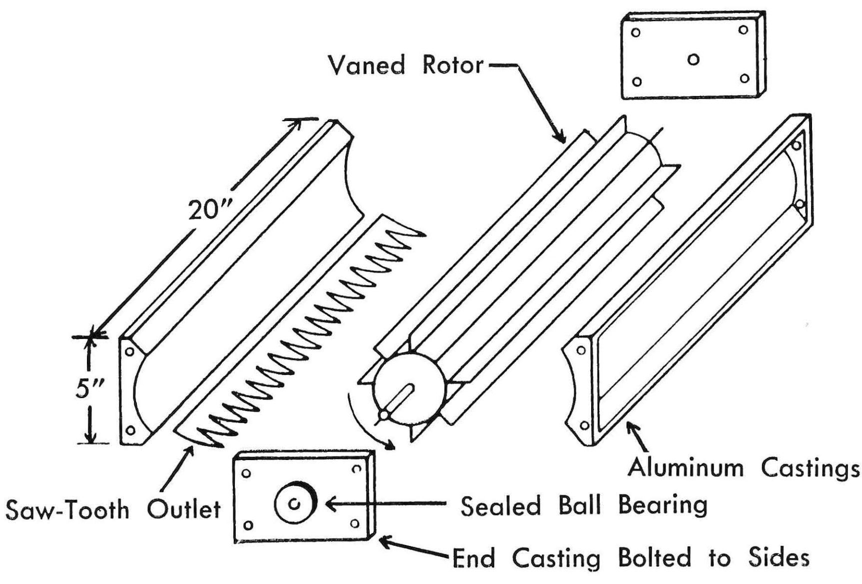

Fig. 15.—Exploded view of the vaned rotor metering device.

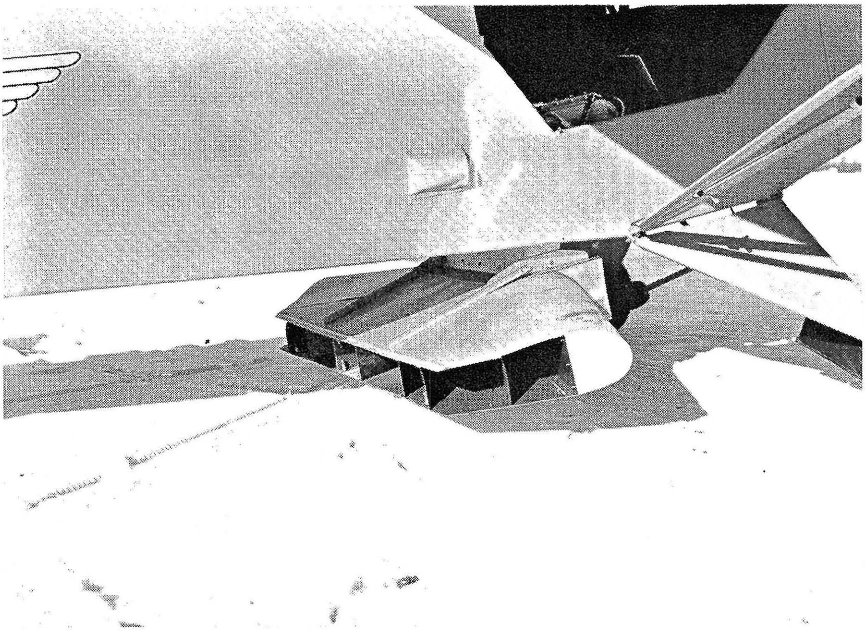

Fig. 16.—Complete distributor showing placement of vanes at the outlet and streamlined leading edge added to reduce the drag and wind buffeting.

edge of the outside vanes to reduce the drag and buffeting. For several of the test runs, a device was attached at the distributor inlet which made it possible to vary the opening depth from 4 inches to 10 inches. Areas were covered at the distributor outlet making the cross-sectional area approximately uniform from front to back (except for the adjustable opening).

Tests were conducted with this distributor in a manner similar to those conducted with the test distributor. Wheat and two coarser sizes of granular clay were distributed in addition to the granular fertilizer and 30-60 mesh clay used with the earlier test equipment.

Results with Test Distributor:

The flight studies confirmed the results of the wind tunnel studies quite well. In addition, results were obtained which could not be determined in the wind tunnel. Using the variable test distributor, it was found that certain variables give somewhat different effects with different materials. For example, when using granular fertilizer the short distributor ($1\frac{1}{2}$-foot section) gave the widest swath, but with 30-60 mesh granular clay the long distributor (3-foot section) produced the widest swath, when no extensions were used (Figure 17).

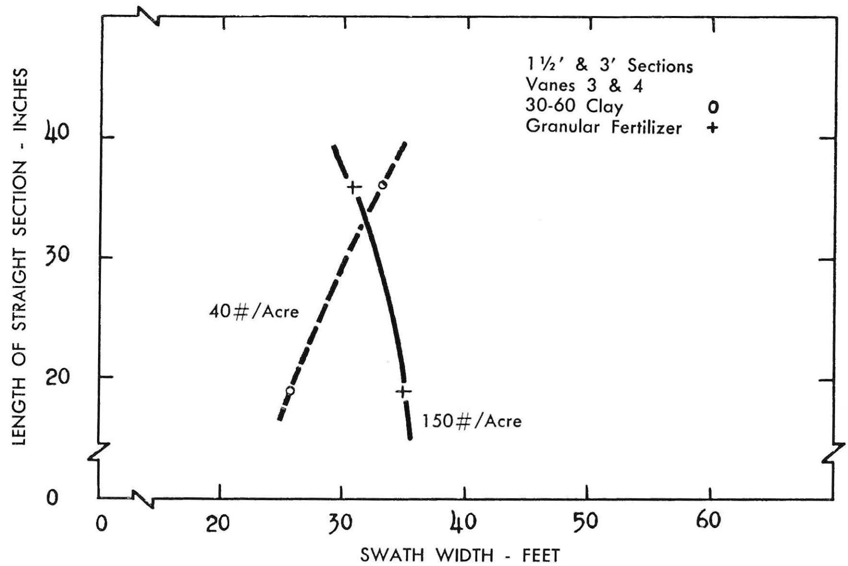

Fig. 17.—Length of the straight section vs the swath width showing the opposing trends of granular fertilizer and granular clay.

In general, the swath width increased as the radii of the deflecting vanes were increased with both granular fertilizer and granular clay (Figure 18). However vanes 3 and 4 gave slightly decreased swath widths as compared to vanes 2 and 3 with the 3 foot section at application rates over 250 pounds per acre of granular fertilizer. This was, no doubt, because of overloading. With the 1½-foot section, vanes 3 and 4 produced the widest swath in all cases.

The swath width increased in practically all cases with an increase in the length of the extensions (Figure 19). However, the extensions were not used with vanes 2 and 3 and 3 and 4 on the 3-foot long section because of insufficient ground clearance. The length of extension appeared to be one of the more important factors contributing to the swath width especially with low density materials such as the granular clay. In all cases the swaths were wider when using the 10-inch extensions than when no extensions were used. The 5-inch extensions gave a slightly wider swath with granular fertilizers when the application rate was over 250 pounds per acre, but in most cases the 10-inch extensions gave a considerably wider swath. This was especially true with the 30-60 clay and the lower fertilizer application rates which would more commonly be used.

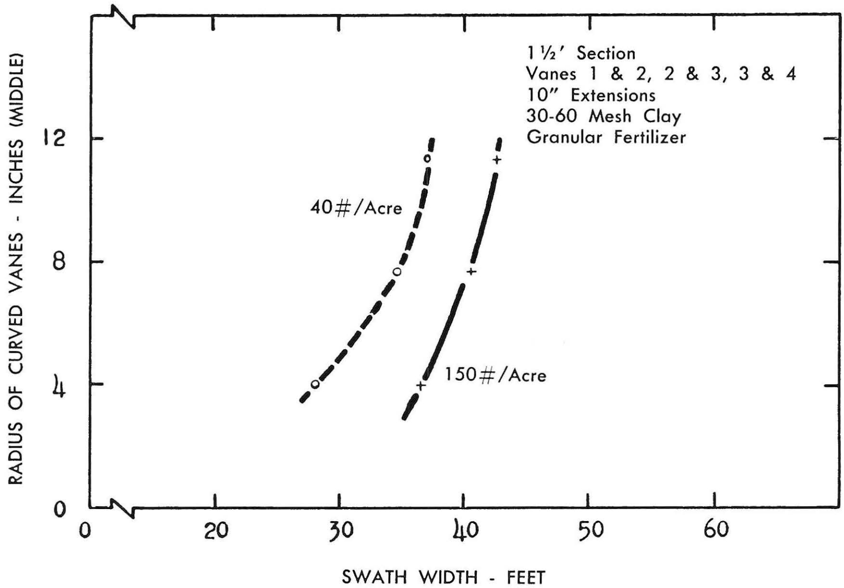

Fig. 18.—Radius of the curved vanes vs the swath width showing the effect of the radius on the resulting swath width. One rate of granular fertilizer and one of granular clay are shown. In general, the trends were similar with other rates. (Clay curve 0; Fertilizer +, Figs. 18-19).

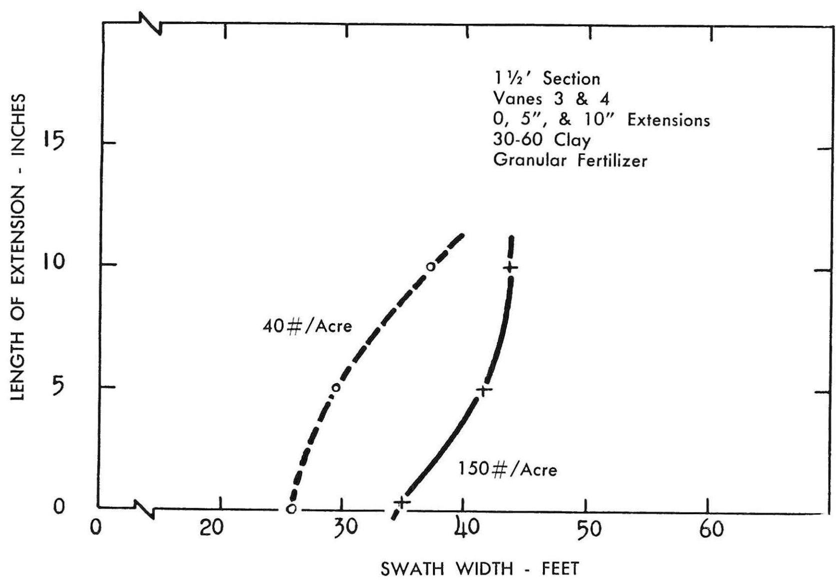

Fig. 19.—The effect of the length of the extensions on the swath width. In general other application rates showed similar trends.

The 70° discharge angle appeared to give a wider swath than the 50° discharge angle with granular fertilizer (Figure 20). Very little or no difference was observed with the granular clay. This may have been due to the variability between the limited number of passes made.

Probably the reason for the decrease in granular fertilizer swath width when using the 3-foot section, vanes 3 and 4 on the 3-foot section at high application rates, or the 10-inch extensions with vanes 3 and 4 on the 1½-foot section, at high application rates, was because of the additional drag from the material remaining in the distributor over a longer distance. This apparently overloaded the distributor to the point where the air flow decreased enough to cause a narrower swath to be produced.

Figures 21 and 22 show the effect of the application rate on the swath width with several of the distributor configurations (see Figure 14) using granular fertilizer and granular clay respectively.

In nearly all cases the air velocity at the distributor inlet was higher when using the distributor configurations which gave the wider swath of granular fertilizer (Figure 23). The air velocities were not measured when using granular clay, but the same would probably be true with most of the distributor configurations used.

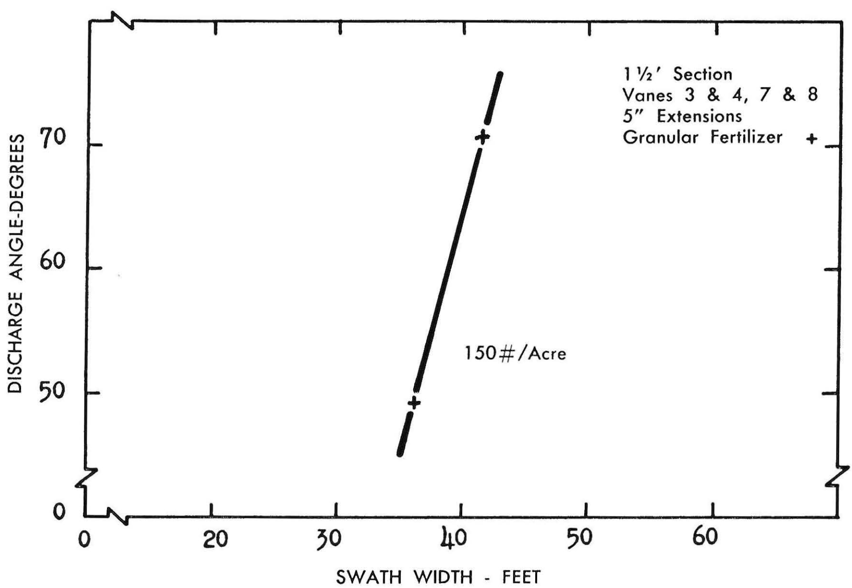

Fig. 20.—The effect of the discharge angle on the swath width.

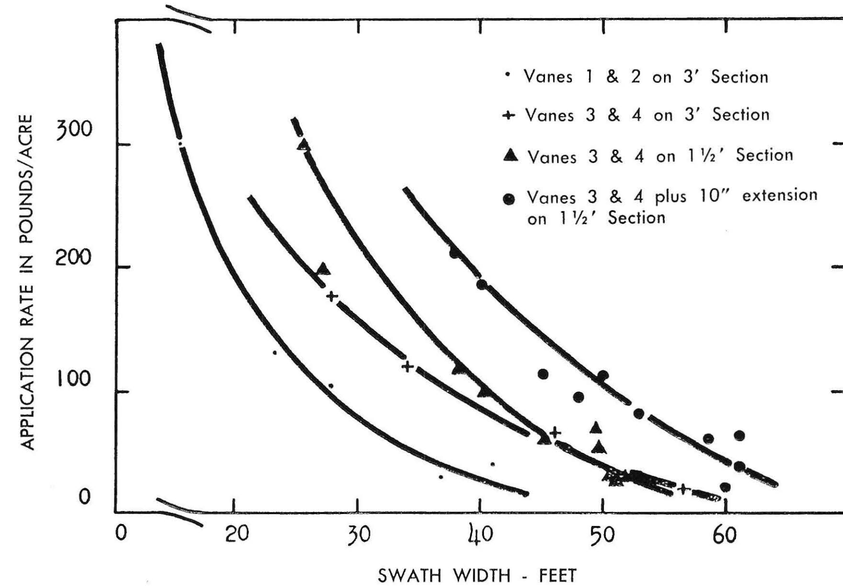

Fig. 21.—Swath width vs application rate for several configurations of the flight test distributor when using a granular fertilizer. See Figure 14 for the distribuutor configurations.

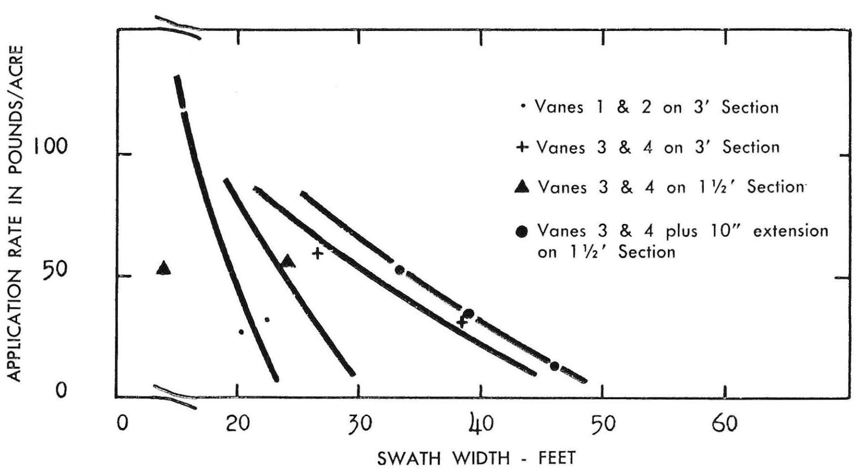

Fig. 22.—Swath width vs application rate for several configurations when using a 30-60 mesh granular clay. The swath width is not the extreme spread but the width that would normally be used for the most uniform overall application.

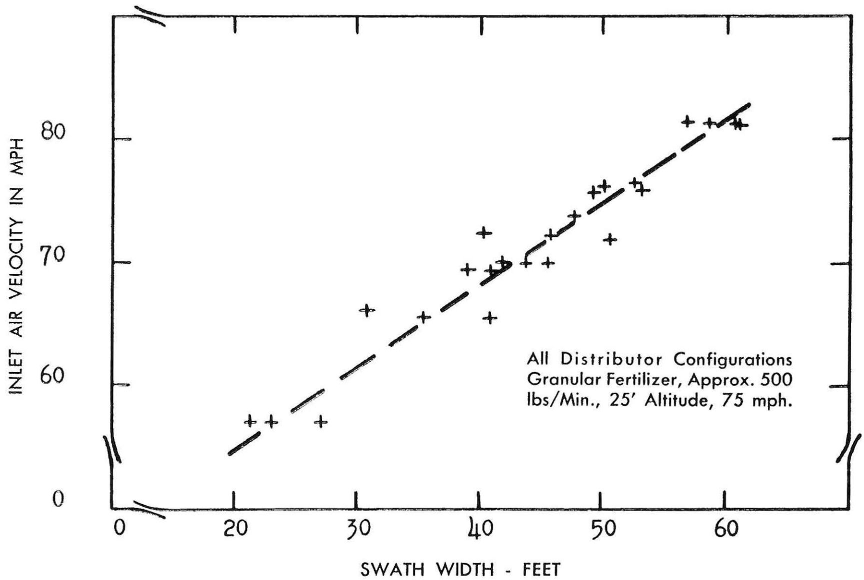

Fig. 23.—Measured swath width vs the inlet air velocity of all of the various flight test distributor configurations.

The air velocities measured in the flight studies seem to agree quite well with what might be expected from the wind tunnel studies in that high velocities are needed to provide a wide swath with heavy granular materials and that the air velocity in the distributor gives an indication of the distributor performance. In general, the air velocities in the vicinty of the flight test distributor were higher than those obtained in the wind tunnel (Figure 23). They were also considerably higher than the air speed of the airplane itself. This was because of the propeller slipstream and the aircraft configuration.

There are at least two major air currents around an airplane which affect the distribution pattern and swath width. They are the propeller slip stream and wing tip vortices. The slip stream is caused by the forces exerted by the propeller in moving the airplane through the air. In general, the slip stream tends to displace the material being applied in the direction of propeller rotation. This would be to the left as viewed in the direction of flight. This action seems to be quite erratic and unpredictable. The wing tip vortex is caused by the air flowing from the high pressure area under the wing to the low pressure area above the wing. This tends to displace the material outward from the underside of the wings. If the material is relatively heavy, it will fall out of the vortex and in this case increase the swath width. If the material is light or of very small particles, it may be caught in the vortex and possibly deposited back towards the center of the swath or may be carried up, caught by crosswinds and drift some distance away.

Results with the complete distributor (Figure 16) appear to agree quite well with the expectations based on the previous studies. Swath widths were about the same as the maximum swaths obtained with the test distributor. With granular fertilizer or wheat, the swath width was approximately 50 feet with an application rate of 100 pounds per acre. At 20 pounds of granular clay per acre, the swath width was approximately 45 feet (Figure 24).

The swath widths as used in this report are not the extreme spread but the width which would normally be used to allow enough overlap for the most uniform deposit over the field.

When the adjustable distributor inlet was in place, the widest swaths were obtained with the opening depth set at eight inches, which is the same as the normal opening size. Slightly narrower swaths were obtained with both the six and ten-inch openings and a considerably narrower swath was produced with the four-inch opening. No change in the drag on the airplane could be detected by observing the air speed indicator.

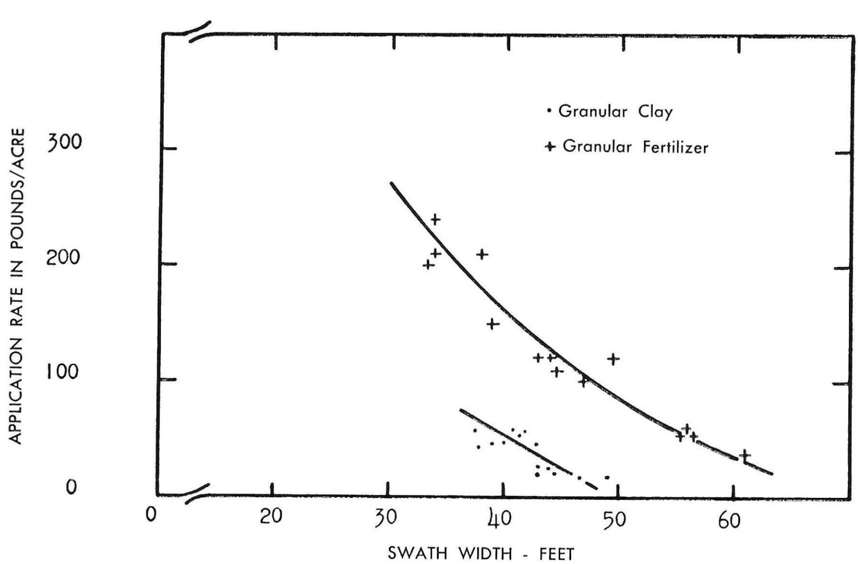

Fig. 24.—Swath width vs application rate for the complete distributor.

Coarse granular clays, (20-30 and 8-15 mesh), appeared to give about the same pattern and swath width as the 30-60 mesh clay (Figures 24 and 25).

The streamlined leading edge (Figures 16 and 26) attached on the front of the outside vanes of the distributor, increased the cruising speed and improved the flying characteristics considerably. After the streamlined leading edge was installed, no buffeting or yawing could be noticed.

After these initial tests were run, the distributor vanes were adjusted to improve the distribution pattern. This adjustment increased the cross-sectional area of several of the channels at the outlet (Figure 26). This improved the distribution pattern some, however, the swath width with light granular clay appeared to be slightly narrower.

Figure 27 shows the cross sections of an idealized pattern and two typical patterns illustrating how unequal or improper spacing will affect the overall distribution pattern.

DISCUSSION

One of the main principles in the design of the ram-air dry material distributor, is that the particles must leave the distributor at a high velocity. By so doing, better lateral and linear distribution can be obtained, also the material will not settle out on the bottom of the distributor causing dribbling or plugging. Of course, the particles will also have to be directed in the proper direction by the distributor.

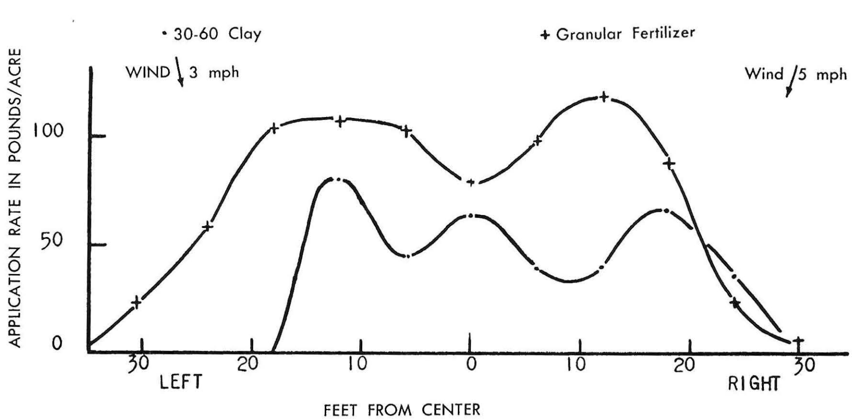

Fig. 25.—Typical deposit patterns obtained with the complete distributor.

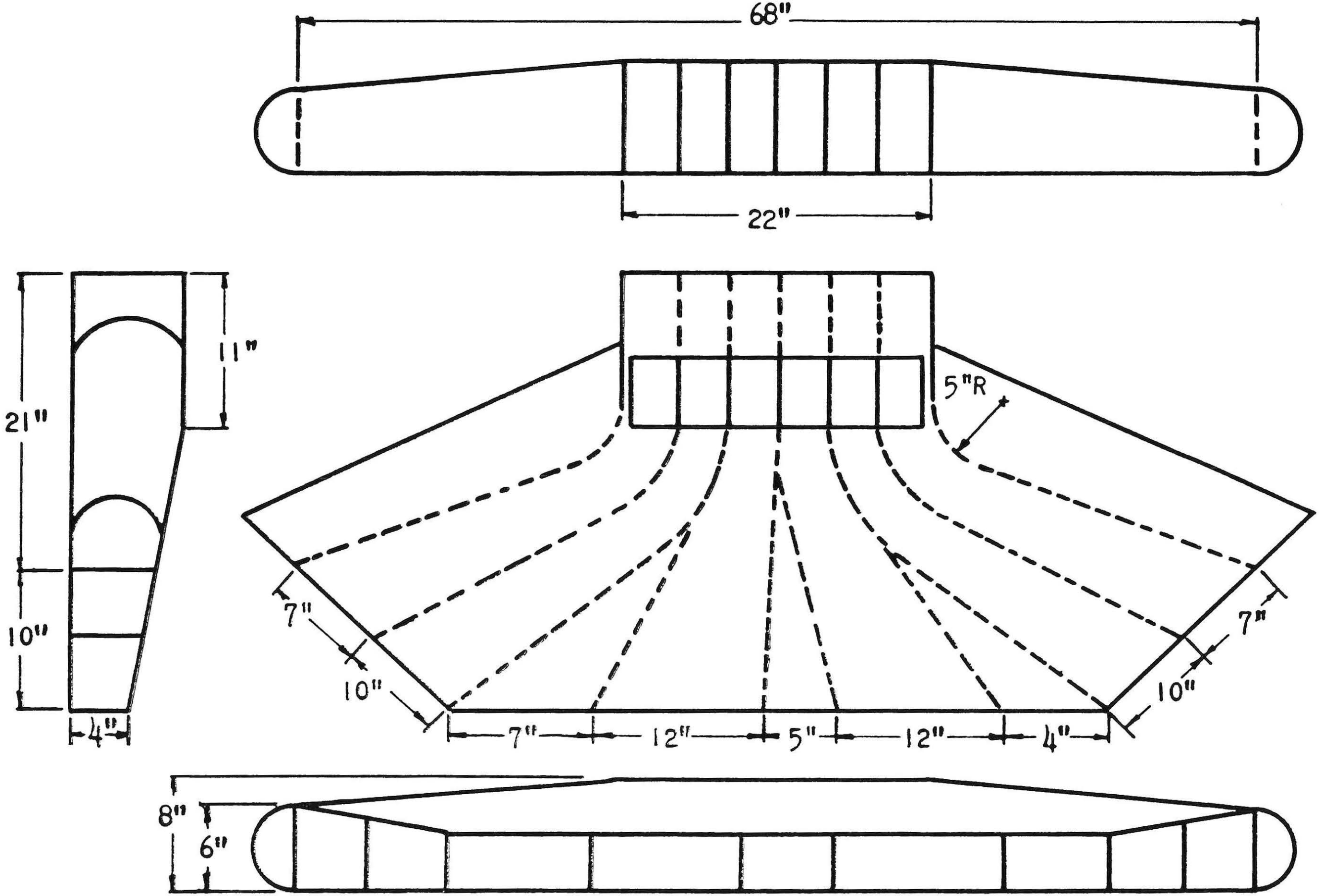

Fig. 26.—The configuration of the "complete" distributor tested. The dashed lines show the location of the interior vanes.

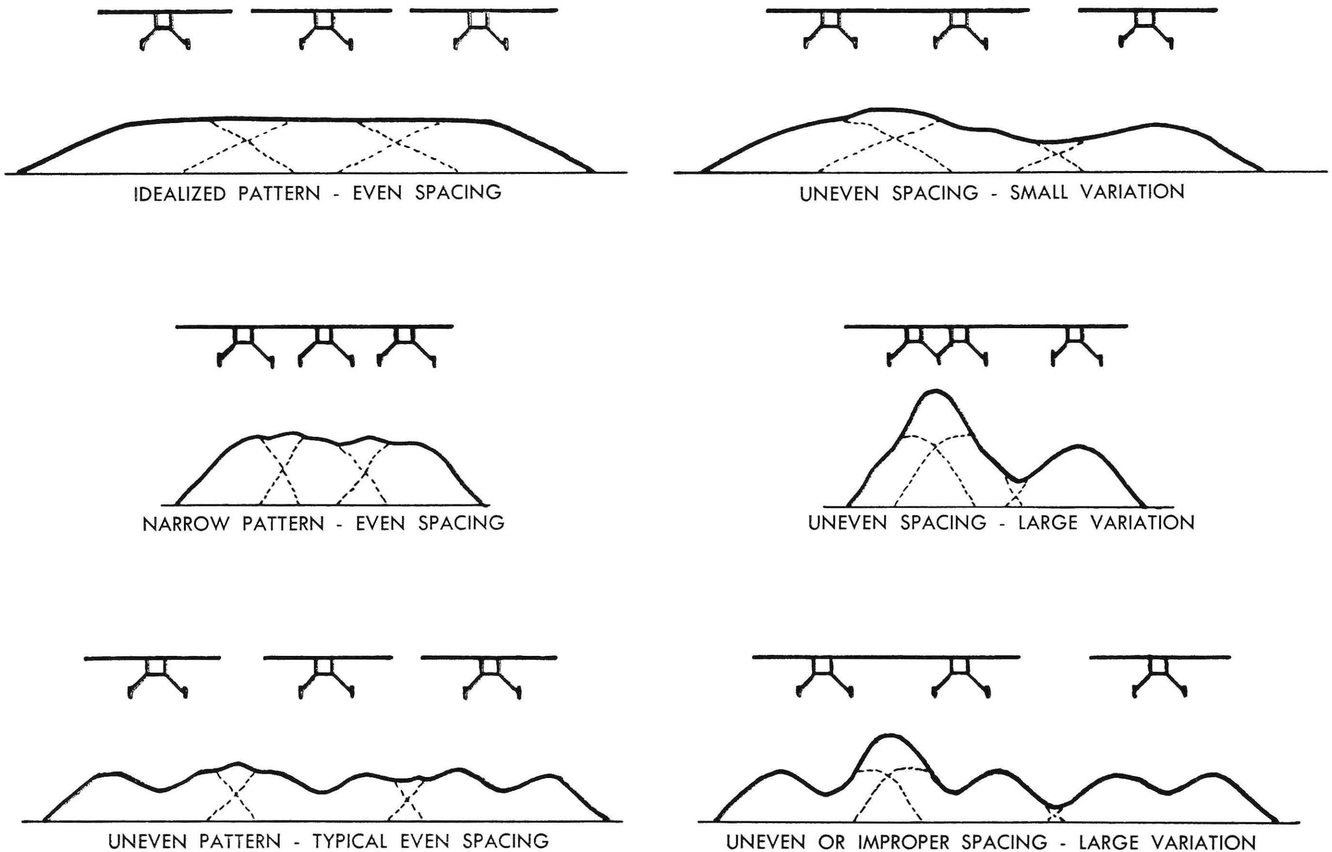

Fig. 27.—Illustrations of ideal and more typical distribution patterns and the effect of uneven or improper swath spacings.

One of the undesirable effects of using ram-air for accelerating the particles is the fact that as the material dispensing rate is increased, the amount of energy available to accelerate a particle decreases. This occurs because the amount of air flowing through the distributor is reduced due to the additional drag on the material while the total (velocity plus static) air pressure remains about the same. Thus, the air velocity, effective in accelerating the material, decreases as the material flow rate increases. These results were evident in the wind tunnel tests because as the dispensing rate was increased, the particle velocity at the outlet decreased (Figure 8). In the flight tests the swath width decreased as the application rate was increased (Figure 21).

CONCLUSIONS

From the wind tunnel studies and the following flight studies of ram-air type distributors, it was indicated that a comparatively large cross-sectional area is necessary to obtain a reasonably wide swath with granular materials. For a light airplane such as used in these studies, it appears that the distributor cross-sectional area at the inlet and outlet should be at least as large as the area of the complete distributor used, which was 176 square inches. It was also indicated that a moderate or no constriction in the throat is the most efficient, which means the throat should be at least 1/2 to 2/3 the inlet area.

In order to obtain a wide swath with a heavy, granular material, such as granular fertilizer or wheat, it appears desirable to have a distributor with a short straight section (deflecting vanes starting immediately behind the chute); moderate radius deflecting vanes (7 to 11 inches as measured in Figure 14); extensions of sufficient length so the material being applied is in the outside channels of the distributor for approximately two feet; and an outlet angle of 50° or more.

For light materials, such as granular insecticides, a longer straight section (deflecting vanes starting some distance behind the chute) might produce a wider swath, although having longer extensions (more overall width at the outlet) would probably be more important. For these materials, the extensions should be long enough so the material would be in the distributor for at least two feet. In addition to having a long distributor, so these materials will be moving through it for some distance, it is no doubt important to have it wide enough so materials will be thrown out beyond the propeller slip stream. For a light airplane then, it would be desirable to have the distributor six feet or more in width at the outlet for obtaining a wide swath with the light materials.

APPENDIX—Wind Tunnel Data-High Speed Movie Series

Run No.	Air Speed - MPH Pitot 1	2	3	4	5	Static Pressure - In. of Water Static 1	2	3	4	5	Lbs. Per Min.	Particle Velocity - Ft./Sec. Distance from Throat 2-4″	6-8″	14-16″	22-24″
						7.5″ Opening, 2.5″ Insert, 2.5″ Throat, Expansion Angle=13°									
3	79	52	127	70	66	.15	1.70	—4.78	—.31	—.07	0				
	77	39	81	36	30	.21	2.45	— .31	—.16	—.02	138	8.21	11.89	14.24	13.60
						7.5″ Opening, No Insert, 7.5″ Throat, Expansion Angle=0°									
4	77	76	75	74	75	.00	.11	.00	—.07	—.06	0				
	77	58	62	60	58	.06	1.21	+ .95	—.01	—.01	136	7.59	11.90	15.90	19.40
						9.5″ Opening, 1.5″ Insert, 6.5″ Throat, Expansion Angle=7.5°									
5	79	77	100	78	76	.01	.10	—2.01	—.17	—.08	0				
	78	55	75	51	47	.12	1.55	+ .23	—.10	—.05	138	9.11	14.70	17.30	16.30 Top
															19.05 Middle
															21.60 Bottom
															20.00 Average
						5.5″ Opening, 1.5″ Insert, 2.5″ Throat, Expansion Angle=7.5°									
6	78	62	118	76	63	.03	1.08	—3.70	—.12	—.08	0				
	77	37	68	20	34	.13	2.28	+ .69	—.10	—.04	138	9.86	14.07	16.86	19.20 Top
															19.40 Middle
															14.53 Bottom
															16.13 Average

Wind Tunnel Data - High Speed Movie Series (Continued)

Run No.	Air Speed - MPH Pitot 1	2	3	4	5	Static Pressure - In. of Water Static 1	2	3	4	5	Lbs. Per Min.	Particle Velocity - Ft./Sec. Distance from Throat 2-4″	6-8″	14-16″	22-24″
						7.5″ Opening, 1.5″ Insert, 4.5″ Throat, Expansion Angle=7.5°									
7	80	74	108	77	72	.04	.37	—2.68	—.16	—.08	0				
	78.5	48.5	74	47	44	.12	1.96	+ .39	—.06	—.04	138	9.04	13.44	16.60	16.00 Top
															18.50 Middle
															18.80 Bottom
															18.60 Average
8	80	74	108	78.5	74	.01	.37	—2.71	—.13	—.08	0				
	78.5	47	73	46	45	.07	1.96	+ .45	—.07	—.05	150	—	—	—	16.90
9	80.4	74	109	79	72	.00	.42	—2.65	—.16	—.06	0				
	80	55	81	53	50	.10	1.65	— .11	—.09	—.03	94	10.41	15.07	21.47	21.70
10	80.4	74	109	79	72	.00	.42	—2.65	—.16	—.06	0				
	80	65	96	66	65	.10	1.08	—1.32	—.10	—.03	39	15.2**	18.82	24.50	26.30
11	100	92	—	98	89	.09	.62	—4.04	—.19	—.08	0				
	99	63	—	61	59	.15	2.81	+ .51	—.10	—.06	138	10.7	16.00	17.70	21.80
12	60	57	83	60	57	.08	.32	—1.55	—.17	—.08	0				
	60	34	58	39	33	.12	1.25	+ .08	—.10	—.04	138	7.48	9.62	12.10	14.22
13	60	57	83	60	57	.08	.32	—1.55	—.17	—.08	0				
	60	34	58	39	33	.12	1.26	+ .08	—.10	—.04	149	6.7	9.28	11.90	12.07
14	80	74	109	78	72	.00	.35	—2.69	—.17	—.08	0				
	78	47	73	45	42	.18	2.08	+ .52	—.10	.00	135*	9.99	13.8	16.61	21.50

*Granular fertilizer on Run No. 14, all other runs wheat.

**4-6″ from throat.

REFERENCES

1. M. L. Upchurch and P. F. Philipp, "Economics of Doing Farmwork with Airplanes," Proceedings of the Third USDA Agricultural Aviation Research Conference, Milwaukee, Wisconsin, November, 1958.
2. G. S. Sanders, "Equipment and Procedures for the Measurement of Deposits of Aerially Applied Materials," Research Bulletin 727, Ohio Agricultural Experiment Station, December, 1953.
3. C. P. Roberts, Mechanical Engineering Department, Ohio State University, Design and Construction of the Vaned Rotor Metering Device Used with Wind Tunnel Study, unpublished.
4. E. H. Kohlman, "Basis of Design for an Adjustable Venturi," Special Problem Report 136, Agricultural Engineering 702-703, March, 1954, Ohio State University.
5. C. E. Lapple, "Factors Affecting Particle Motion in a Fluid," Industrial and Engineering Chemistry, page 605, Volume 32, 1940.
6. Circular on construction of a wind vane for use by spray applicators, Texas Agricultural Experiment Station Progress Report 1466.
7. J. E. Henry, "A Device for Metering Dry Materials," mimeographed paper presented at the Texas Agricultural Aviation Conference, Texas A & M, February, 1957.

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